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An ocean flux study in eutrophic, mesotrophic and oligotrophic situations: the EUMELI program

ANDRÉ MOREL*

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PREFACE

Within the framework of the French participation in the Joint Global Ocean Flux Study (JGOFS), the EUMELI project was conceived in the years 1987–1989 and initiated with the first cruise in July 1989. Four additional cruises followed and the project was terminated in December 1992 (see Table 1). The general objective of the program was the study of the main processes that govern particle fluxes, from their creation within the upper layers by photosynthetic activity to their burial in the bottom sediments. The strategy was to carry out such a study at three sites, selected as being typical of three trophic regimes, namely the EUtrophic, MEsotrophic and oLIgotrophic regimes (hence the acronym). The ultimate goal is to develop, improve and start to validate a series of models allowing the biogeochemical fluxes towards and within the interior of the ocean to be related to near-surface algal content and photosynthetic activity and, in the future, to variables accessible by remote sensing techniques, such as ocean color, temperature, irradiation and wind.

The selected sites (Table 2 and Fig. 1), all located in the tropical northeast Atlantic at approximately 20°N, are characterized by roughly similar climatic conditions and a reduced seasonal variability. As shown by the ocean color imagery (Fig. 2(a)), these sites strongly differ, in phytoplankton abundance at all seasons. The algal standing stock is always high in the quasi-permanent Mauritanian upwelling area, whereas it is steadily very low at the periphery of the North Atlantic gyre. The mesotrophic site is in an intermediate position; a

Table 1. *Cruises of the EUMELI program (see also map, Fig.* 1*)*

No.	Dates	Research vessel	Remarks
1	1–28 July 1989	R.V. *Charcot*	1 leg; 3 sites visited.
2	9 January–22 February 1991	R.V. *l'Atalante*	2 legs; 3 sites visited; hydrographic survey around the 3 sites.
3	14 September–24 October 1991	R.V. *l'Atalante*	2 legs; eutrophic site not visited; Sites IMO, T1, T2, T3 visited (CTD + core parameters)
4	18 May–30 June 1992	R.V. *l'Atalante*	2 legs; 3 sites visited, plus EM-01 to 04 and MO-01 to 03.
5	7–30 December 1992	R.V. *Le Suroît*	1 leg; all sites visited (as for EUMELI no. 4).

* Laboratoire de Physique et Chimie Marines, Université Pierre et Marie Curie and CNRS, BP 8, F-06230, Villefranche-sur-Mer, France.

Table 2. Location and bottom depths of the stations visited during EUMELI

Oligotrophic site	21°00 N	31°00 W	4600 m
MO-01	20°25	28°35	4850
MO-02	19°42	25°52	4500
MO-03	19°05	23°30	3935
Mesotrophic site	18°30	21°00	3090
EM-01	18°53	20°30	3280
EM-02	19°18	20°00	3330
EM-03	19°43	19°32	3245
EM-04	20°08	19°03	3075
Eutrophic site	20°32	18°36	2030

less stable trophic status was expected in such a location, which episodically is under the influence of extended filaments detached from the upwelling zone (Fig. 2(a)). The large differences in primary production between the three sites (by a factor of about 10, see Fig. 2(b)), which presumably result in different ecological chains and biogeochemical processes, can facilitate the understanding of the mechanisms controlling the fate of the organic carbon (and associated elements) throughout the water column and also across air–sea and water–sediment boundaries.

In addition to the regular cruises (every eight months, starting with the second cruise), sediment trap deployement was an essential component of the EUMELI program. Lines equipped with specifically designed conical traps (collecting area 1 m^2, 24 receiving cups,

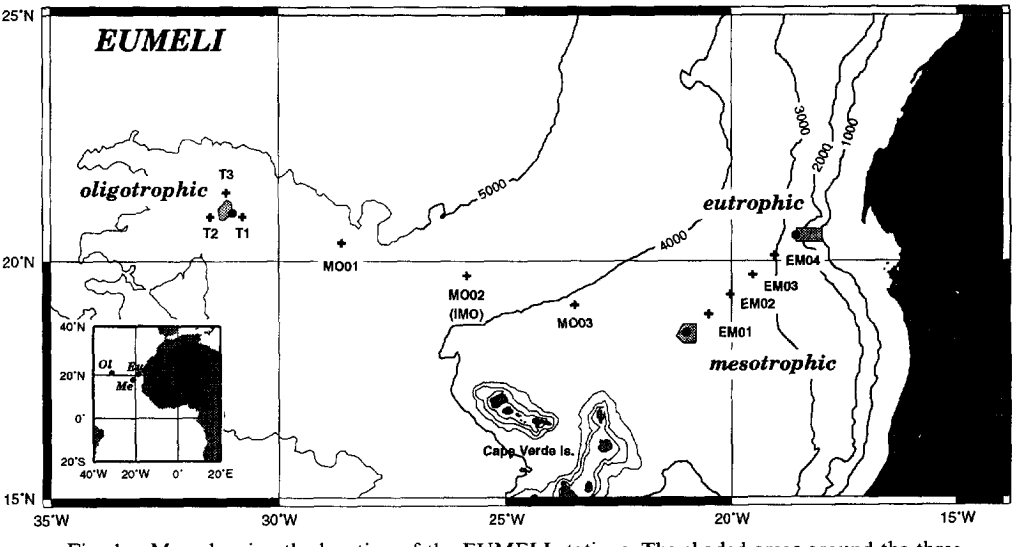

Fig. 1. Map showing the location of the EUMELI stations. The shaded areas around the three main sites (eutrophic, mesotrophic and oligotrophic sites) represent the zones of intensive CTD casts performed during cruise no. 2.

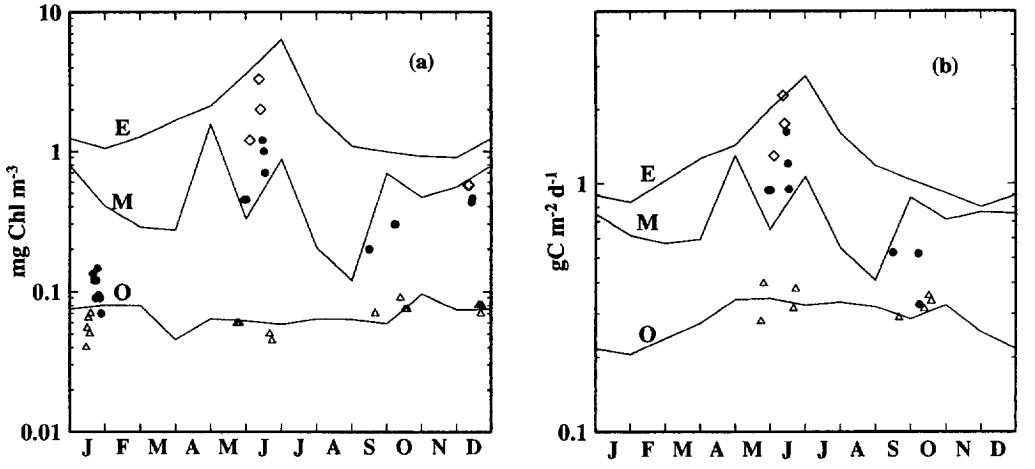

Fig. 2. (a) Annual cycle of the chlorophyll concentration within the surface layer at the three sites (denoted E, M and O); these values have been extracted from the twelve "climatological monthly maps" derived from the CZCS NASA archive (see Morel *et al.*, 1996). Measured values during the cruises, from no. 2 to no. 5 (see Table 1), are also shown with the following symbols: diamonds, closed circles and triangles for the eutrophic, mesotrophic and oligotrophic sites, respectively. (b) Annual cycle of the primary production at the three sites computed by using a standard model (denoted "version 2" in Morel *et al.*, 1996), operated with the chlorophyll concentration of panel (a), and temperature and cloud climatologies. The field determinations are also displayed, with the symbols as in (a), and for cruises 3 and 4 only.

sampling intervals about 10 days) were moored at the oligotrophic and mesotrophic sites (not at the eutrophic site, located inside Mauritanian waters). This deployment, over three consecutive periods, lasted about 2 years. Five traps and associated Aanderaa current meters were moored at the oligotrophic site (bottom depth 4600 m), at 250, 1000, 2500, 4400 and 4590 m depths; and four were moored at the mesotrophic site (bottom depth 3090 m), at 250, 1000, 2500 and 2890 m depths.

The cruise EUMELI no. 1 was essentially devoted to a detailed topographic survey of the pre-selected sites, using swath bathymetry techniques, sidescan sonar and sea floor imagery. First, studies and inventories of the benthic communities were carried out, and sediments were sampled by sediment piston and box coring. It was found that the sedimentation rates, at least over the last 10 000 years, are regular and reflect the main features of the primary productivity in the upper layers at the three sites. It was also ascertained that no significant perturbations, such as those induced by hydrothermal activity, occur at the sites or in their vicinity (Auffret *et al.*, 1992). This stability was a prerequisite for a meaningful interpretation of the sediment trap results.

During EUMELI no. 2, emphasis was put on a comparative examination of the benthic ecosystems at the three sites (Sibuet *et al.*, 1993). The relationships between these ecosystems and the physical environment, the flux of matter reaching the bottom and the biogeochemistry of the surficial sediment were investigated (Rabouille *et al.*, 1993a,b). For this purpose, short-term deployment of specific instrumentation (benthic chambers, respirometers, *in situ* incubators and baited traps), as well as intensive sampling of sediments (multicorer and large box corer), were effected (Legeleux *et al.*, 1994a,b). Radionuclide activities in trapped sinking particles and in sediments were compared

(Legeleux *et al.*, 1995). A first hydrological survey including 39 CTD casts to the bottom (see map) was conducted around the three sites with a view to identifying the details of the water masses (Vangriesheim *et al.*, 1993). The oxygen and carbon stable isotope composition was also determined (Pierre *et al.*, 1994), together with several JGOFS core parameters.

During the sister cruises, EUMELI nos 3 and 4, the major activity was focused on the water column and particularly on its upper part; benthic studies were pursued, but less intensively. Most of the JGOFS core parameters were determined in a systematic and repetitive way. Primary production was measured by clean techniques and the recommended protocols; the "let-go" device was simultaneously operated (Dandonneau and Le Bouteiller, 1992). Nutrients at the nanomolar level were measured according to a recently published method (Raimbault and Pujo-Pay, 1993; Pujo-Pay and Raimbault, 1994). The photosynthetically available radiation (PAR) was monitored on-deck and in-water, and the spectral composition of the downwelling and upwelling irradiances were determined within the euphotic layer. Spectral absorption by particulate matter, and by algal cells only, was recorded (Bricaud *et al.*, 1995), together with the fluorescence excitation spectra of the phytoplankton. This optical program was closely coordinated with the pigment analyses, both by HPLC (Claustre, 1994; Claustre and Marty, 1995) and by spectrofluorometry (Neveux and Lantoine, 1993). Picoplankton identification and enumeration were carried out by flow-cytometry, and the properties of these tiny cells were compared to those observed *in vitro* (Morel *et al.*, 1993). By use of a specially designed incubator (Babin *et al.*, 1994), the parameters of the P versus E (photosynthesis–irradiance) curve were accurately determined, whereas the photochemical efficiency of photosystem 2 was determined by the active stimulated fluorescence technique, or "pump and probe" fluorometry (during EUMELI no. 4). Several papers in the present issue deal with the results of the above described program.

The set of data related to the photo-physiological characteristics of various algal communities found at the three sites, as well as the results related to the bio-optical properties of the water masses, allow adjustments of primary production models to be made (Antoine and Morel, 1996). Heterotrophic bacterial biomass and bacterial activity throughout the water column and zooplankton distribution and migration were regularly investigated. In support of the sediment trap program and *in situ* pumping experiments, samples were also collected for several trace metals, natural radionuclides, dissolved organic carbon (500 samples) and specific organic compound estimations.

During EUMELI no. 4 and no. 5, seven additional stations, regularly spaced along the transect connecting the three sites, were occupied (Table 2). The objective was to obtain a more detailed description of the hydrographic regime in the entire EUMELI zone (see also the study by Dadou and Garçon, 1993) and of the distribution along these sections of the main JGOFS parameters. On several transects, the CO_2 partial pressure in the surface water, pH and chlorophyll fluorescence were continuously monitored (Copin-Montegut and Avril, 1995). A total of 402 CTD casts (with rosette sampling) were obtained, mostly shallow (250 or 500 m deep) and regularly spaced in time (usually every 3 h, but every hour in some instances). Deep casts, to the bottom, were performed several times at each site (systematically at the beginning and end of the site occupation period). A significant atmospheric sampling program was scheduled during the cruises 3 and 4 for aerosols and sulfur compounds (Belviso *et al.*, 1993; Putaud *et al.*, 1993). The microbial web and zooplankton grazing appear to play an important role in the transfer of these compounds (Corn *et al.*, 1994).

The last cruise, EUMELI no. 5, aboard a smaller research vessel, was devoted to the final recovery of the long-term moorings. The measurements were restricted to the JGOFS core parameters, without the time series at each site made in the previous cruises, nos 3 and 4. A sixth cruise was initially planned in the program but was abandoned for logistic reasons, as the R.V. *L'Atalante* was scheduled for various operations in the Pacific Ocean. The initial plan was transformed into a comparative study of the oligotrophic regimes in the Atlantic and in the Pacific, with the same kind of motivation and goals as put forward for EUMELI. This cruise, under the acronym OLIPAC, was realized in November 1994.

The EUMELI samples are not yet entirely analyzed, and results not fully exploited, though several specific studies are already published (see References, below). In the present special section, a series of papers resulting from the EUMELI project is presented. They were submitted through the normal channels and thus subjected to the regular review process, involving the journal's Editorial Board.

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